Application of Bent Crystals At IHEP 70-GeV Accelerator To Enhance The Efficiency Of Its Usage

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Abstract

Bent crystal was extracting 70-GeV protons with average intensity 4×10^{11} (as measured in external beamline) per spill of $\sim$1.6 s duration, in parallel to the simultaneous work of two internal targets in the accelerator ring. An additional crystal, placed in the external beamline, was deflecting a small part of the extracted beam with intensity $\sim10^7$ protons toward another physics experiment. Crystal-extracted beam had a typical size of 4 mm by 4 mm *fwhm* at the end of the external beamline. Measurements for the extraction efficiency and other characteristics at the simultaneous work of four experimental set-ups are presented. With crystal working in the above-said regime during one month, no degradation of channeling was observed. The studies of extraction efficiency have been continued with new crystals.

1 Studies of beam extraction by means of bent crystal

Since 1997 at the IHEP 70 GeV accelerator we carried out studies of proton beam extraction by means of bent silicon crystals [1-4]. These studies pursued the realization of a pure multiturn extraction using short, 5 to 3 mm, O-shaped crystals (see Fig. 1) with small bendings of 2 to 0.5 mrad. Such a small bending of a crystal is insufficient for direct extraction of the beam out of accelerator. Therefore, crystals served as primary element in the existing scheme of slow extraction.

Crystals with bendings of 1.5 to 2 mrad were installed in straight section 19 of the accelerator before the septum-magnet OM-20 of the slow extraction system and provided a kick of the deflected beam into the aperture of this magnet with partition thickness of 8 mm (Fig. 1).

Another series of crystals with bendings of 0.5-1 mrad were installed in straight section 106 (not shown in Fig. 1); here the extraction of the crystal-deflected beam was

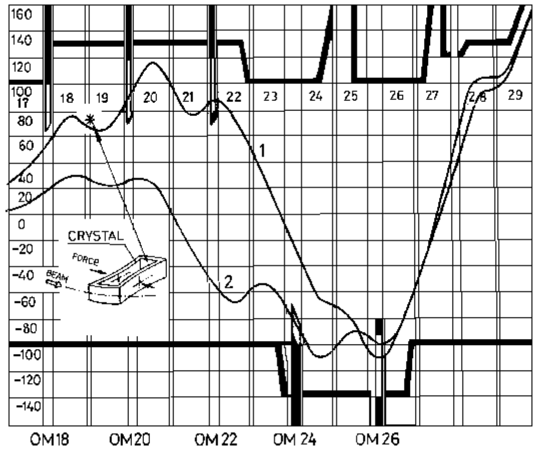

Figure 1: The scheme of the accelerated-beam extraction via septum-magnets OM-20 (curve 1) and OM-24 (curve 2). The inset shows O-shaped crystal.

performed through the septum-magnet OM-24 with partition thickness 2.5 mm (Fig. 1, curve 2).

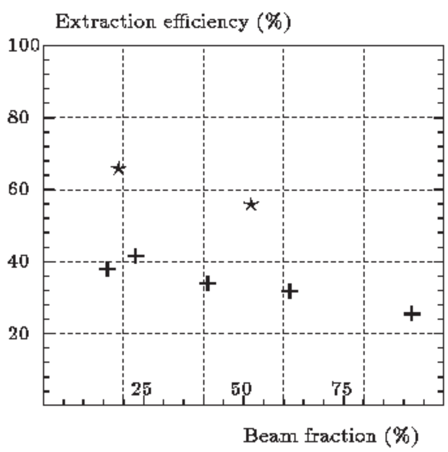

Figure 2: Spill-averaged efficiency of extraction as measured with 3-mm crystal 0.9 mrad bent ($\star$), March 2000; 5-mm crystal 1.5 mrad bent (+), March 1998; plotted against the beam fraction taken from the accelerator.

To direct the accelerated beam onto the crystals, the local orbit distortion systems were used working in the regime of close loop operation. The obtained efficiencies are plotted in Fig. 2. The accuracy of the beam extraction efficiency measurements was about 4%. For 20% of the accelerator beam intensity dumped onto the crystal, the measured extraction efficencies were 42% for the 5-mm crystal with 1.5 mrad bending and 65% for the 3-mm crystal with 0.9 mrad bending, installed in straight sections 19 and 106 respectively. The reduction of extraction efficency with increase of the beam fraction dumped onto the crystal is due to the drift of the beam angle at a crystal because of the tilted phase ellipse. During the studies of the extraction efficiency, for a short period of time ($\sim$1 hour) the regimes of beam extraction of intensity $\sim 1.2 \cdot 10^{12}$ protons per cycle were exploited.

2 Example of practical usage of bent crystals at IHEP accelerator

The obtained high efficiencies of the beam extraction with use of bent crystals open new ways for setting up new physical experiments at accelerators. As an example, let us consider one of the schemes for the practical usage of bent crystals realized at U-70 accelerator and shown in Fig. 3.

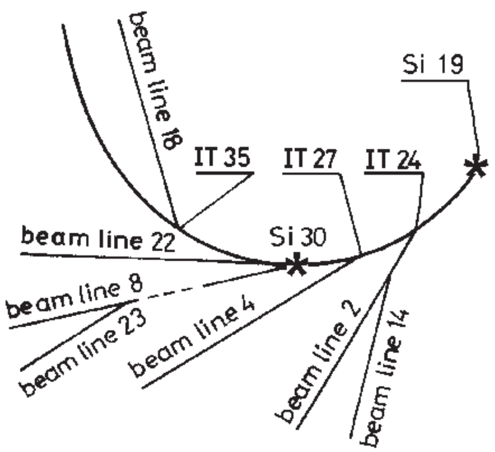

Figure 3: One of the schemes of practical usage of bent crystals realized at U-70 accelerator.

By means of 1.5 mrad bent crystal Si19 (straight section 19) the proton beam of up to 4×10^{11} p/cycle intensity was extracted into beamline 8 and directed into beamline 23 onto the target of the experimental set-up used for the studies of $K^{\pm}$-mesons decay modes into three π-mesons: $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$. As the K^{+}-meson yield is about 20 times higher than that of K^{-}, with the transfer from K^{-} to K^{+} the intensity of the extracted proton beam had to be reduced by the same factor. This procedure was repeated regularly with 24 hours period.

Along the path of the extracted beam, at the beginning of beamline 8 another crystal Si30 bent $\sim$9 mrad was positioned to deflect a small fraction of the beam (up to 10^{7} protons per cycle) into beamline 22. Simultaneously with crystals Si19 and Si30, two internal targets IT24 and IT27 were working, supplying negatively-charged beams of up to 10^{7} particles/cycle intensity into beamlines 2 and 4 respectively. Besides the physical studies on these four beamlines (22, 23, 4, and 2), methodical work was feasible on the test beamline 18.

To direct the accelerated beam onto crystal Si19 and two internal targets IT24 and IT27 along the flattop of magnet cycle 1.6 s long, three local orbit distortion systems were used in the regime of close loop operation.

Fig. 4 shows the intensity of secondary beams in beamline 2 and in the set-up at beamline 23 in the K^{+} and K^{-} work regimes. For a time about 27 days, the Si19 crystal has obtained an irradiation of the order of 10^{20} proton/cm^{2}. Herein the crystal channeling properties have not changed, as comes directly from the measurements of beam extraction efficencies in the beginning (44$\pm$2 %) and in the end (43$\pm$2 %) of the run.

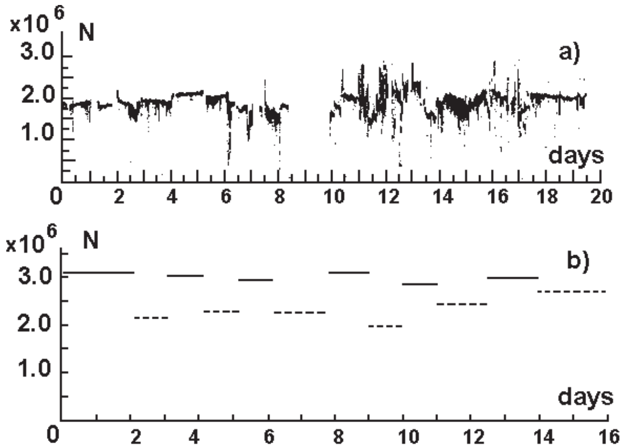

Figure 4: The intensity N of secondary beams in beamline 2 (a) and in the set-up at beamline 23 (b) in the K^- (solid) and K^+ (dashed) work regimes

The first experience of the work with the above-considered system, although satisfied the physicists, has also revealed ways for further advancement (improvement of the local orbit distortion systems stability, possibility to increase the intensity in the K^+ and K^- regimes on the set-up of beamline 23 etc.).

3 Further plans

As computations show, the efficiency of beam extraction can be raised with use of shorter (order of 1 mm and less) bent crystals.

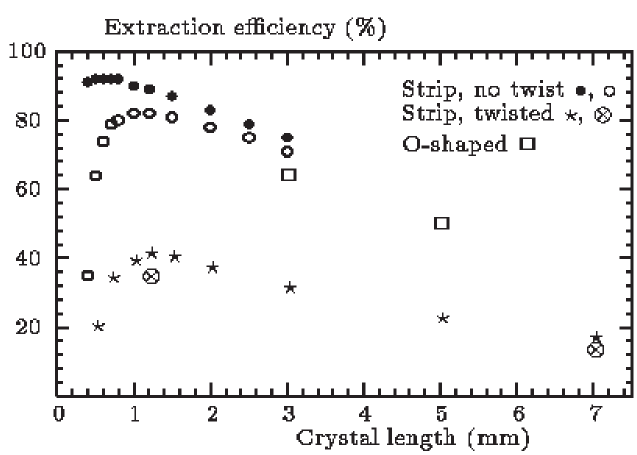

Figure 5: Simulated efficiency of 70-GeV proton extraction by a crystal "strip" 40 mm high, 0.27 mm thick, with bending of 0.9 mrad. No twist (•, o); either perfect bending (•) or bending over half of the full length (o). Below are shown ($\star$) the results with twisted crystal (6 μrad/mm^2). Also shown are the experimental results of 1997-2000 with strips ($\otimes$), 1.2 mm and 7 mm long, and O-shaped crystals ($\square$), 3 mm and 5 mm long.

Besides the high energy accelerators, crystals of this kind could be used also at low energy accelerators. Basic problem here is to bend such a crystal at an angle of 0.5-1.5 mrad. One of radical solutions for this problem is to obtain bent crystals in the process of crystal growth [5]. Another direction, now in progress in IHEP, is related to the methodics of bending a short strip.

The above said is illustrated by Fig. 5 where plotted are the calculations of extraction efficiency for the most interesting, still-unstudied region, and the experimental data obtained at the IHEP accelerator.

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